The Morphology of Flash Boiling LN2 Sprays in High-Altitude Liquid Rocket Engines

Dipl.-Ing. **A. Rees**, Institute of Space Propulsion, German Aerospace Center (DLR)

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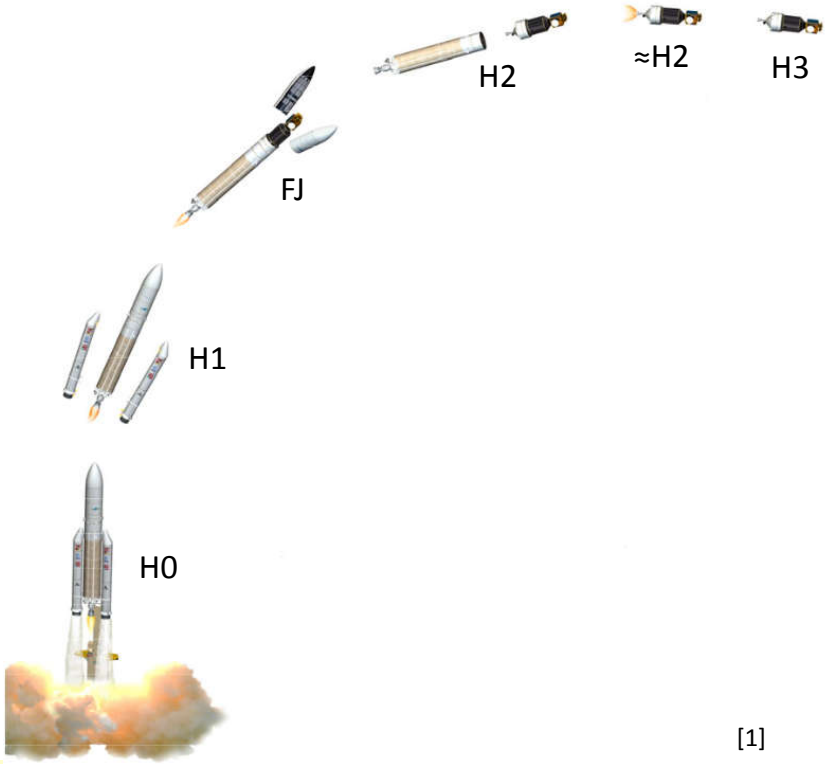
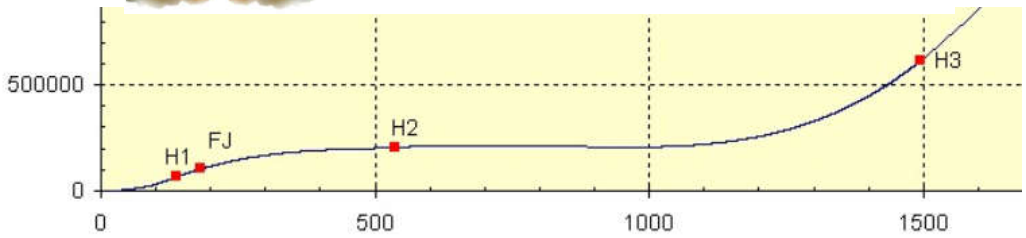
Superheat & Flash boiling (I)

- Re-ignitable upper stage engines
- New engine & propellant systems for RCS engines
  - → cryogenic oxygen (LOX), other green propellants
- LOX injection into vacuum (superheated condition)
  - → Flash evaporation
- Characteristics of spray important for ignition process
  - → ignition?
  - → combustion stability?

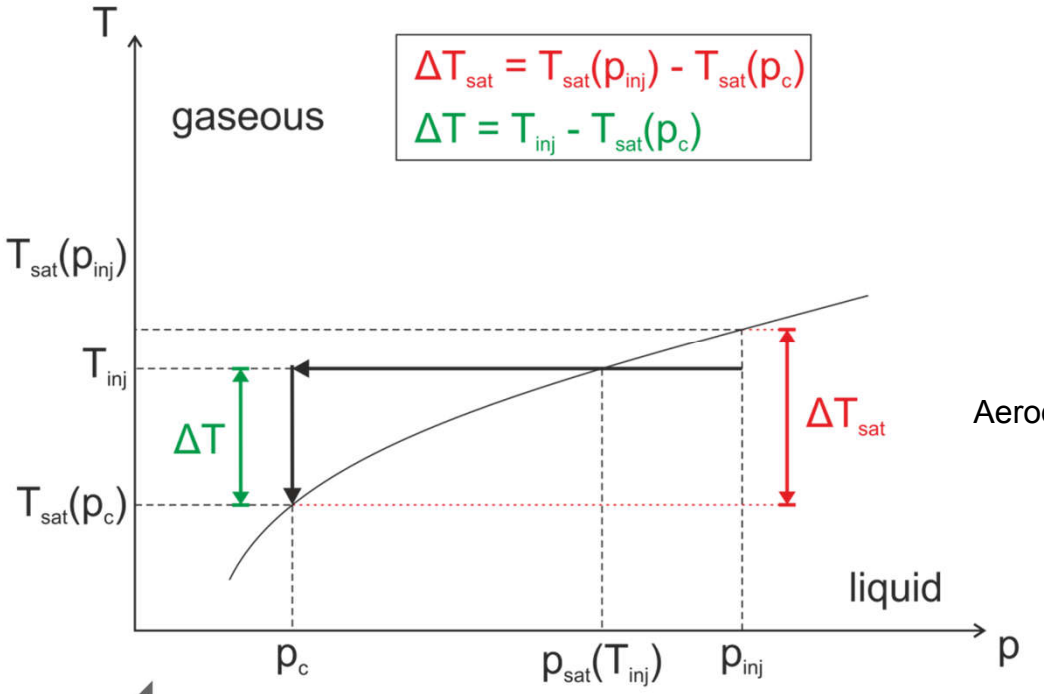


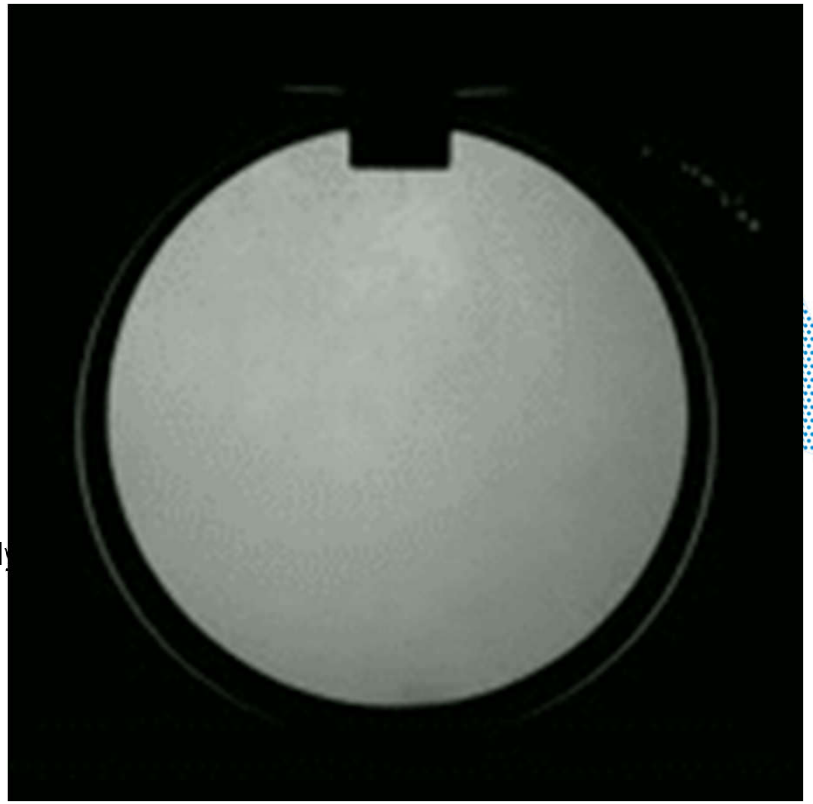
[1]



Superheat & Flash boiling (II)

- Degree of superheat: $\Delta T^{*} = \frac{\Delta T}{\Delta T_{sat}} = \frac{T_{inj} - T_{sat}(p_c)}{T_{sat}(p_{inj}) - T_{sat}(p_c)}$ or $R_p = \frac{p_{sat}(T_{inj})}{p_c}$

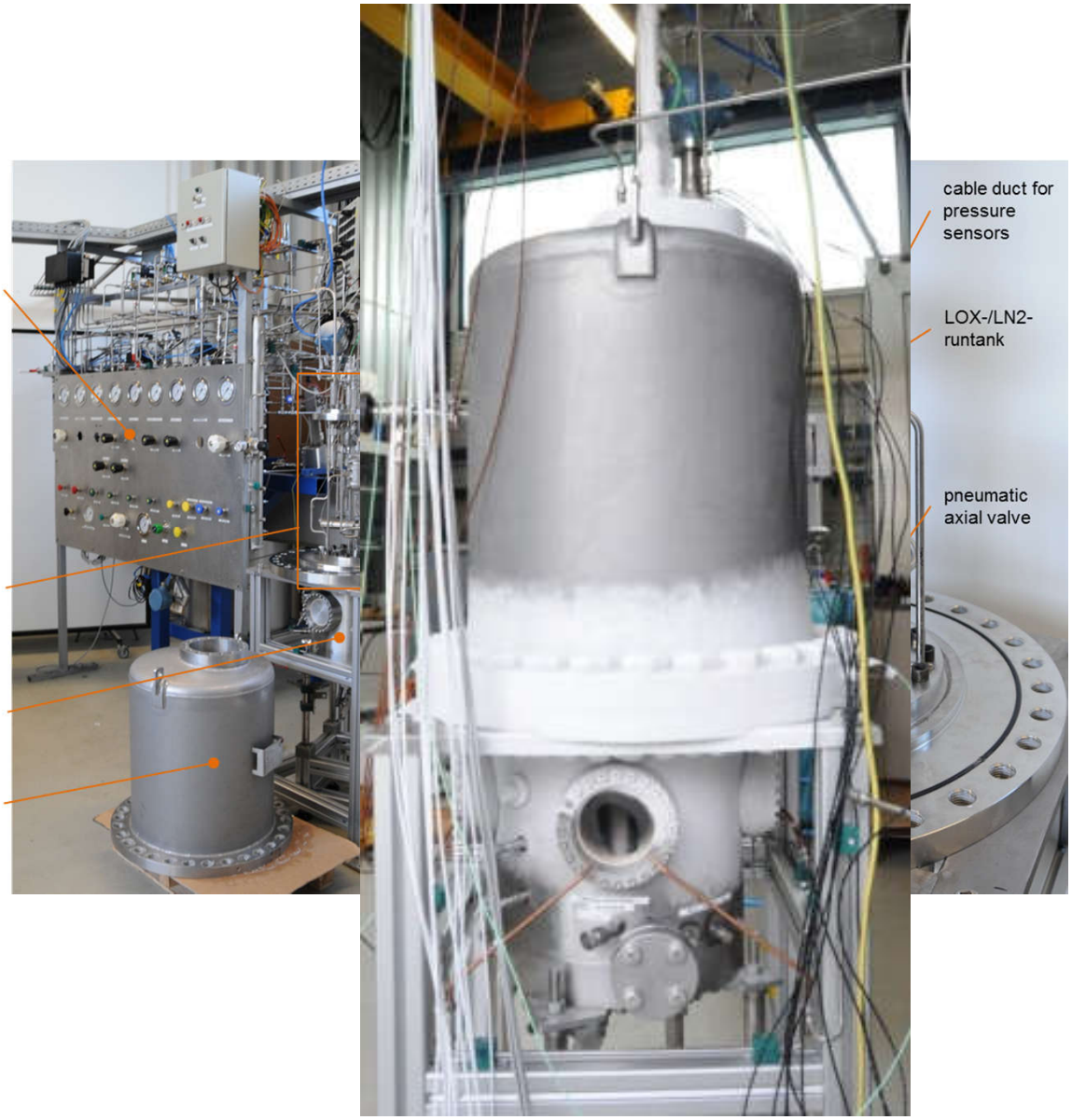




Aerody

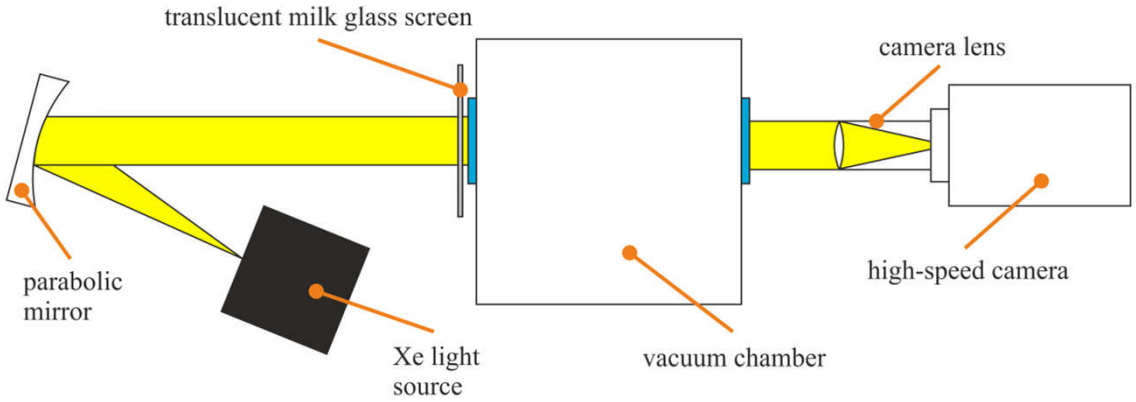
Test bench M3.3

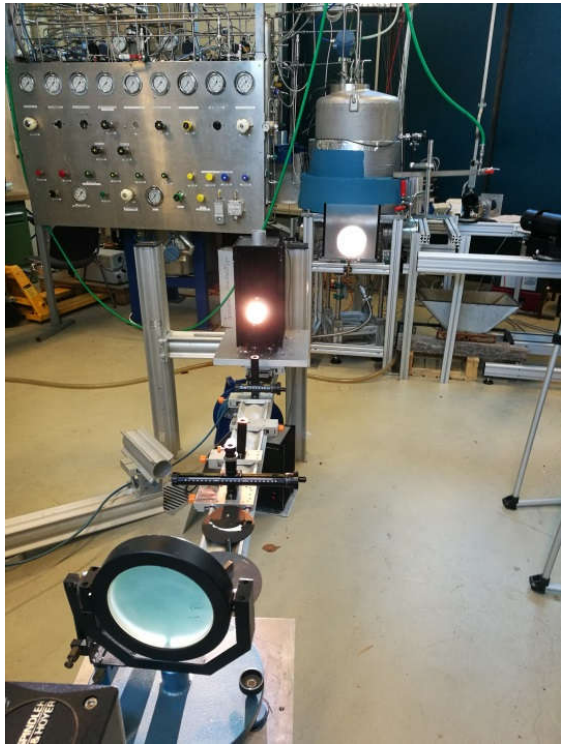
- Cryogenic temperature adjustment and injection system: LN2 pressure tank, LN2 run tank and injector unit
- Vacuum system
- Chill-down of the test bench

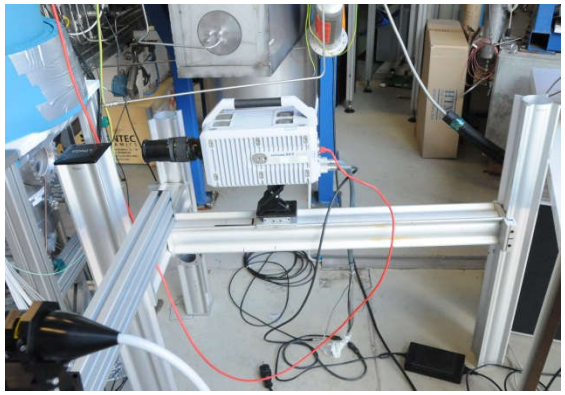


Optical Setup

- Backlight Shadowgraphy
  - Fastcam SA-X
  - Xe light source
  - Translucent milk glass screen
  - 10.000 fps
  - 1024x1024



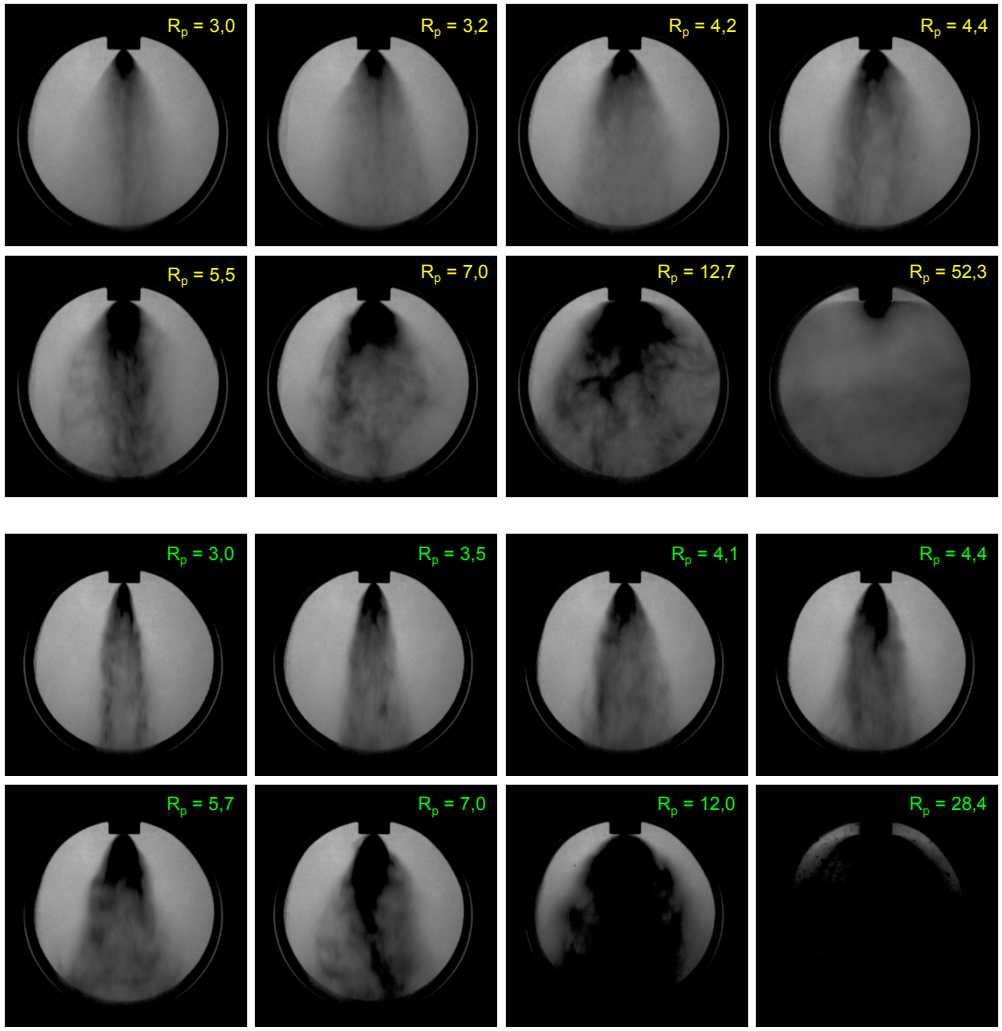




Shadowgraphy Camp. LN2 (I)

- T_{inj} = 82,5 K (±0,6 K)
- D_{inj} = 1 mm
- p_c = 36-600 mbar

- p_{inj} = 4 (±0,2) bar
- p_{inj} = 8 (±0,3) bar



start injection + 120ms

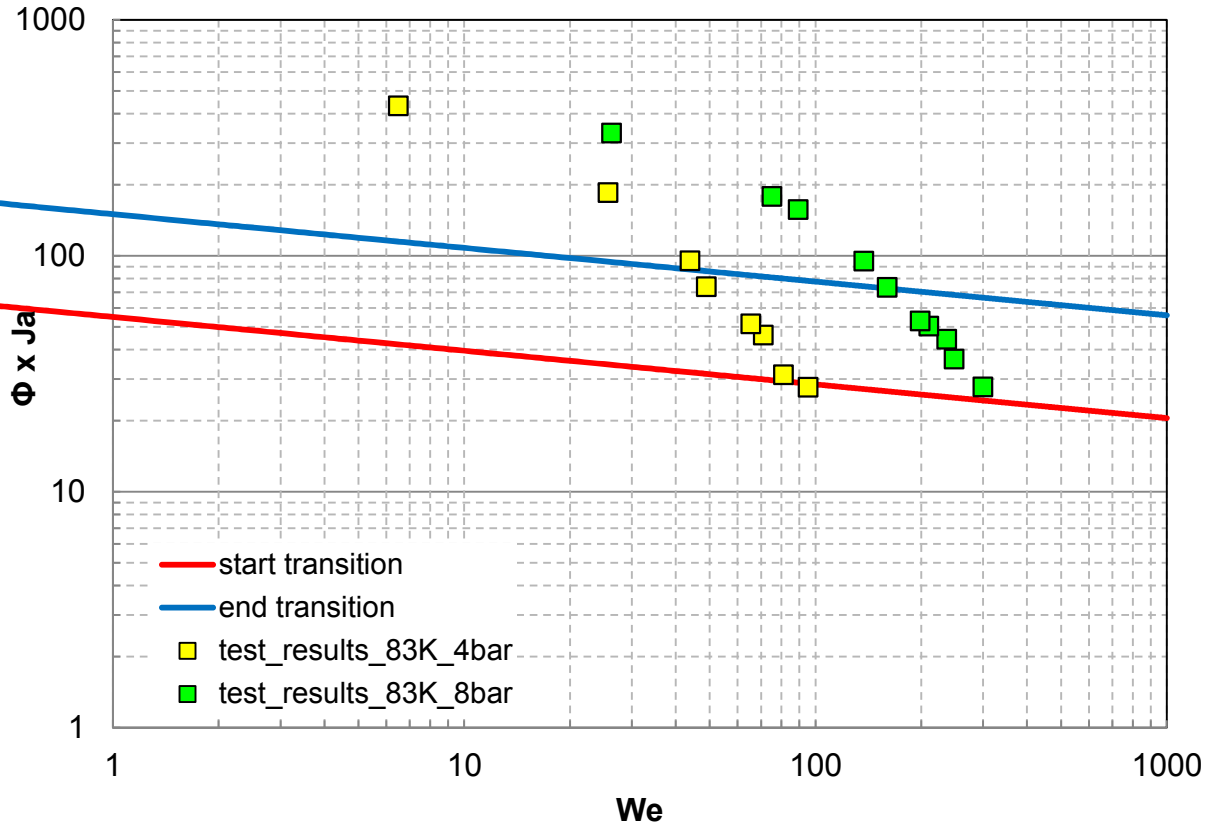
Shadowgraphy Camp. LN2 (II)

- T_{inj} = 82,5 K (±0,6 K)
- p_{inj} = 4 & 8 (±0,3) bar
- D_{inj} = 1 mm
- p_c = 36-600 mbar

$$\mathrm{We} = \frac{\rho_g u^2 d}{\sigma}$$

$$\mathrm{Ja} = \frac{\rho_\mathrm{l} c_\mathrm{pl} \Delta \mathrm{T}}{\rho_\mathrm{g} h_\mathrm{vap}}$$

$$\Phi = 1 - e^{-2300*\left(\frac{\rho_g}{\rho_L}\right)}$$



Blue and red lines by Cleary et al. [2]

Conclusions and Outlook

- test bench with cryogenic injection system provides reproducable, constant and homogeneous injection conditions
- evolution of LN2 sprays with increasing R_p → fully flashing sprays
- variation of p_{inj}: different spray patterns despite R_p = const. → other definition for degree of superheat
- Flashing LN2 sprays fit into transition correlations for storable fluids

- determination of spray angles, droplet size and velocity distributions

→detailed data base of flash boiling LN2 sprays for numerical modelling and validation

Literature

[1] E. Perez, Ariane 5 User's Manual, Issue 5 Revision 0, July 2008.

[2] V. Cleary, P. Bowen, and H. Witlox, Flashing liquid jets and two-phase droplet dispersion - I. Experiments for derivation of droplet atomization correlations, *J. Hazard. Mater., 142*, pp. 786-796, 2007.